OBPMark and OBPMark-ML – Computational Benchmarks for On-Board Data Processing and Machine Learning in Space Applications

David Steenari*, Ivan Rodriguez*†‡, Sanath Muret*, Marc Solé Bonet†‡, Jannis Wolf†‡, Luis Mansilla*, Leonidas Kosmidis†‡

*:European Space Agency, Noordwijk, Netherlands, †Barcelona Supercomputing Center (BSC), Barcelona, Spain,
‡Universitat Politecnica de Catalunya (UPC), Barcelona, Spain

The high-level objectives of OBPMark are:

- To promote a standard set of benchmarks, as a recurrent method of comparing end-user performance of different devices and systems – such as both RHBD and COTS processors, FPGAs and ASICs.
- To better understand limitations of different types of devices and systems.
- To assist in deciding the division of tasks in hardware and software for implementations in heterogeneous systems.
- To allow ESA to quickly provide recommendations for processing systems in future space missions, through identifying key parameters together with the project teams.
- Benchmark standard on-board processing functions, so that implementers will have the possibility of reusing the invested work in real-world use cases and flight projects.

The following high-level requirements were considered when defining OBPMark:

- Coverage:
  - ...shall cover common OBP applications: image processing, compression, radar processing, encryption, common building blocks (for radar, radiometry, SDR, etc) and machine learning.
  - ...shall include representative inputs from space missions or space-relevant software
  - ...shall allow the addition of future benchmarks through version update.
- Comparable:
  - ...shall provide comparable results for: overall performance, performance / power, absolute power.
  - ...shall provide all necessary configuration parameters
  - and test data.
- Portable:
  - ...shall provide reference software in standard C.
  - ...shall provide reference implementation in standard parallelization schemes: OpenMP, OpenCL and CUDA.
  - ...shall be possible to port to FPGA and other hardware-specific implementations.
  - ...shall allow end-user software/hardware optimizations.
- Openness:
  - ...shall be openly available (open-source license, open repository).
  - ...shall be open for community response/feedback.
  - ...shall be open for community contributions (porting etc.).
- Reproducibility:
  - ...reference input and output datasets shall be included
  - ...results shall be validated against the reference outputs in order to ensure correctness

Vendor	Device Name	Type	Seq.	OpenMP	OpenCL	CUDA	Custom	ML Framework	Benchmark results includes
Frontgrade Gaisler	GR712RC	Multi-core CPU	X	X				TFLM	
Frontgrade Gaisler	GR740	Multi-core CPU	X	X				TFLM	
NXP	LS1046A	Multi-core CPU	X	X				TFL	X
NXP	LX2160A	Multi-core CPU	X	X				TFL	X
AMD Xilinx	Zynq7000	FPGA SoC	X	(x)				Vitis AI	
AMD Xilinx	Zynq UltraScale+	FPGA SoC	X	(x)				Vitis AI	X
AMD Xilinx	Kintex Ultrascale KU060	FPGA						Vitis AI	
AMD Xilinx	Versal AI Core VC1902	FPGA SoC	X	(x)				Vitis AI	X
AMD Xilinx	Versal AI Core VE2302	FPGA SoC	X	(x)				Vitis AI	
Microchip	PolarFire SoC	FPGA SoC						VectorBlox	
AMD / Unibap	ix5	GPU SoC	X	X	X			TFM	X
NVIDIA	TX2	GPU SoC	X	X		X		TFM	
NVIDIA	Xavier NX and AGX	GPU SoC	X	X		X		TFM	X
NVIDIA	Orin NX and AGX	GPU SoC	X	X		X		TFM	X
Intel	Myriad 2 & X	DSP SoC						OpenVino	
ISD/ASD	HPDP	DSP SoC					X		
Ramon Space	RC64	DSP SoC	X				X		
OCE Technology	Hisaor	GPU SoC	X	X	X			TBA	

TABLE IV
SELECTION OF HARDWARE TARGETS AVAILABLE IN THE BENCHMARKING FACILITY.

The OBPMark benchmark suite consist of the following three parts:

1) OBPMark - Application benchmarks
2) OBPMark-ML - Machine learning inference benchmarks
3) OBPMark-Kernels - Common algorithm building block benchmarks

# ID	Benchmark name	Data size / Settings
#1.1	Image Calibration and Correction	2048x2048, 16-bit
#1.2	Radar Image Processing	2752x14357
#2.1	CCSDS 121.0 Data Compression	2048x2048, 16-bit
#2.2	CCSDS 122.0 Image Compression	2048x2048, 16-bit
#3.1	AES Encryption	16.8M words (4096x4096), Key length: 256

TABLE V
BENCHMARKS USED DURING THIS STUDY.

ID	Benchmark Name	Type	Algorithm
ML-#1	Cloud Screening	Semantic segmentation	CNN / U-Net
ML-#2	Ship Detection	Object detection	CNN / YOLO
ML-#3	CME Classification	Image classification	CNN

TABLE II
OVERVIEW OF OBPMARK-ML BENCHMARKS.

Benchmark Name	Type
CIFAR 10	Object detection
CIFAR 10 Multiple	Object detection
Convolution 2D	Convolution kernel
Correlation 2D	Correlation kernel
FFT	Fast-Fourier Transform
FFT 2D	2D Fast-Fourier Transform
FFT Window	Fast-Fourier Transform Window
FIR Filter	Finite-Impulse Response Filter
LRN	Local response normalization
MM	Matrix Multiplication
Maxpool	Maximum pooling kernel
Memory Bandwidth	Memory bandwitth
Relu	Rectified linear unit kernel
Softmax	Softmax kernel
Wavelet	Wavelet transform

TABLE III
OVERVIEW OF OBPMARK-KERNELS (GPU4S_BENCH) BENCHMARKS.